SOLID-PROJECTILE HELICAL COIL ELECTROMAGNETIC LAUNCHER*

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Abstract

Helical coil electromagnetic launchers (HCEML's) can operate at significantly lower currents and higher efficiency in comparison to conventional railgun and induction coilgun launchers. The HCEML's versatility is due, in part, to its large inductance gradient which is typically 2 to 3 orders of magnitude greater than conventional railguns and can be tailored to practically any value in that range. The University of Missouri-Columbia (MU) has focused on the development of a low current, high efficiency launcher for low to medium velocity applications. To this end, MU has demonstrated a 40 mm bore x 750 mm length HCEML's to launch ~500 gram projectiles to 150 m/s operating at 12 to 15 kA peak currents, 400 to 800 V peak voltages, and measured efficiencies as high as 32%. While this particular HCEML used hollow-projectiles, present research efforts at MU are focused on the development of a solid-projectile HCEML. This investigation describes a 40 mm bore x 300 mm length solid-projectile HCEML. The goal of this research is to demonstrate the solid-projectile HCEML concept and to experimentally measure its performance.

I. INTRODUCTION

HCEMLs have been studied by many investigators in the past [1-3]. Only recently, however, have the technical issues associated with this launcher (i.e., commutation and achievable inductance gradient) been solved [3]. In fact, the HCEML of is the most electrically efficient launcher reported in the literature (i.e., up to 32%) and operates at much lower current than same-scale conventional and augmented railguns (15 kA compared to 100's of kA) [3]. The hollow-projectile HCEML is one of only a few EMLs that have its components externally accessible to diagnostics, both optically and electrically. While accessibility is useful in terms of research, hollow projectiles limit the usefulness of the launcher to only certain applications. It is, therefore, advantageous to develop a solid-projectile HCEML to extend launcher's scope of applications.

The basic construction of the solid-projectile HCEML is shown in Fig 1. Power is supplied through the internally-located rails to the projectile. From the rails, the power is supplied to the armature located inside the projectile. Annular brushes [4] route the power to energize a section of the stator. As drawn, the magnetic field from the armature and stator repel each other. Thus, as the armature moves, the brushes are relocated with it thereby changing the energized section of the stator.

This investigation reports the design and construction of a 40 mm bore x 300 mm length solid-projectile HCEML. While efficiency and low current operation are certainly concerns for this research, the primary goal of the investigation is to demonstrate the feasibility of the solid-projectile HCEML concept. To the author's knowledge, this is the first operational solid-projectile HCEML has been reported in the literature. The focus of future research will be to improve the HCEML design and to increase its performance to levels comparable to and, ultimately, exceeding, existing hollow-projectile HCEMLs.

II. THEORY

The electromagnetic force generated in any launcher is an important parameter when designing it. The HCEML operating with constant current has a force given by [3]

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14. ABSTRACT

Helical coil electromagnetic launchers (HCEMLs) can operate at significantly lower currents and higher efficiency in comparison to conventional railgun and induction coilgun launchers. The HCEMLs versatility is due, in part, to its large inductance gradient which is typically 2 to 3 orders of magnitude greater than conventional railguns and can be tailored to practically any value in that range. The University of Missouri- Columbia (MU) has focused on the development of a low current, high efficiency launcher for low to medium velocity applications. To this end, MU has demonstrated a 40 mm bore x 750 mm length HCEMLs to launch ~500 gram projectiles to 150 m/s operating at 12 to 15 kA peak currents, 400 to 800 V peak voltages, and measured efficiencies as high as 32%. While this particular HCEML used hollow-projectiles, present research efforts at MU are focused on the development of a solidprojectile HCEML. This investigation describes a 40 mm bore x 300 mm length solid-projectile HCEML. The goal of this research is to demonstrate the solid-projectile HCEML concept and to experimentally measure its performance.

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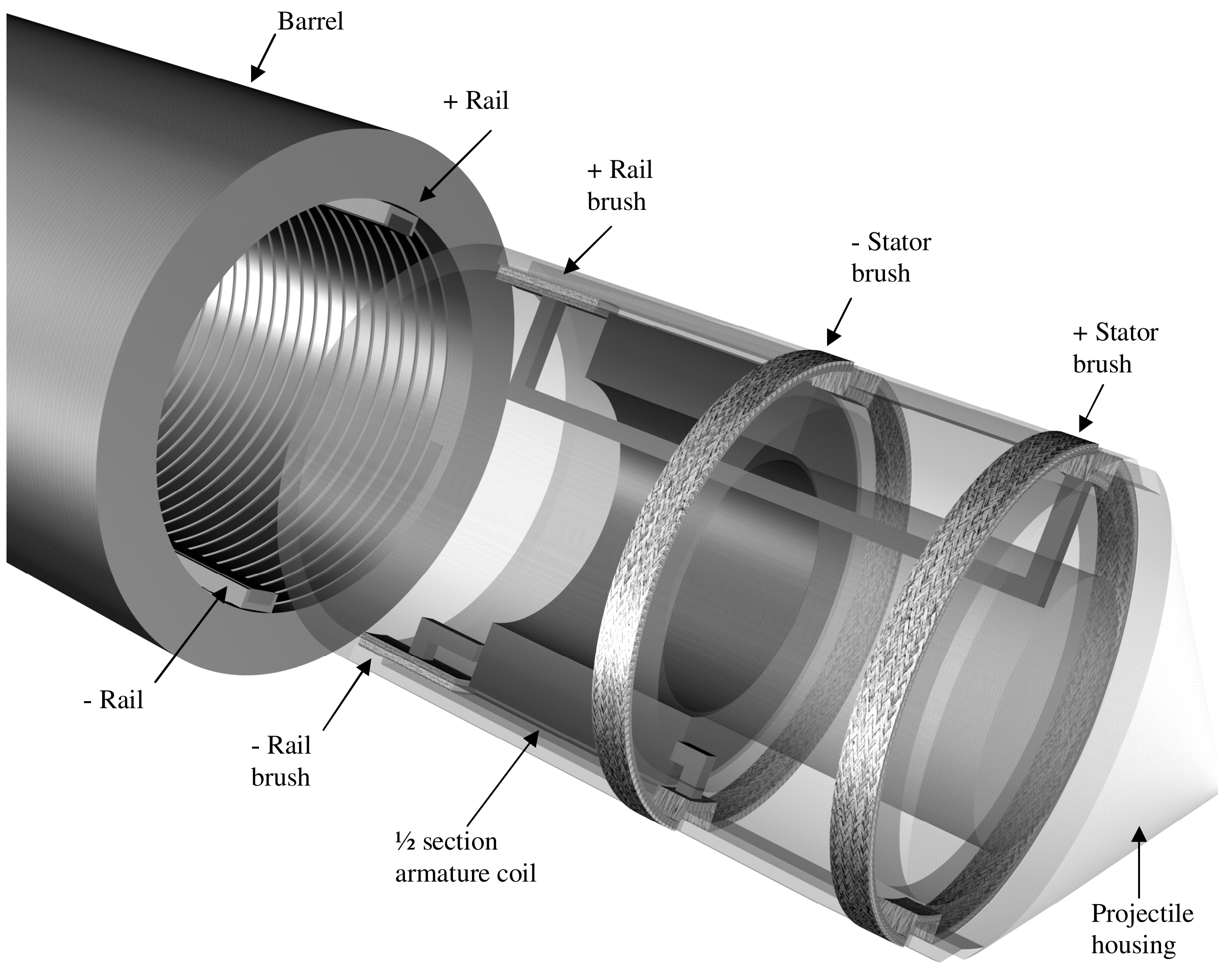

Figure 1. Basic construction of the solid-projectile HCEML illustrating its components.

$$\begin{aligned} F &= \nabla W_i \\ &= \frac{d}{dx}\left(\frac{1}{2}L_{eq}I^2\right) \\ &= \frac{1}{2}\frac{d}{dx}\left(L_{eq} = L_a + L_s \pm 2M\right)I^2 \\ &= \pm M' I^2 \end{aligned} \tag{1}$$

where L_{eq} is the equivalent inductance, L_a is the armature self-inductance, L_s is the stator self-inductance, M is the mutual inductance between the stator and armature coil, M' is the mutual inductance gradient, and I is the launcher current. The HCEML typically operates with series-connected armature-stator coil pair. Positive M' indicates an attractive electromagnetic force between the armature and stator coils while a negative M' indicates a repulsive force.

Another important parameter for any launcher is the electrical-to-kinetic energy conversion efficiency. The HCEML efficiency is given by the expression [3]

$$\begin{aligned} \eta &= \frac{\eta_{\max}}{1+\dfrac{\sigma}{v_{\max}}} \\ &= \frac{\eta_{\max}}{1+\dfrac{R_s}{M' v_{\max}}} \end{aligned} \tag{2}$$

where $\eta_{\max}$ is the maximum conversion efficiency and equal to 50% for the launcher in this investigation, σ is the launcher's characteristic velocity and equal to R_s / M', R_s is the total system resistance, and $v_{\max}$ is the maximum projectile velocity. If a large acceleration force is desired, (1) shows more gains can be made by increasing the force rather than the inductance gradient. In terms of efficiency however, (2) suggests a large mutual inductance gradient and small system resistance is advantageous. Eq (2) also states that conversion efficiency increases with projectile velocity.

III. LAUNCHER CONSTRUCTION

The construction of the solid-projectile HCEML is shown in Figs 2 through 4. Fig 2 is an end-view of the HCEML barrel and rail mounting assemblies. The barrel is constructed from G-10 fiberglass-reinforced epoxy. The stator coil within the barrel is constructed from 14 gauge square copper-chrome wire. Fig 3 shows the projectile with its annular and rail brushes. The projectile is also constructed from G-10 fiberglass-reinforced epoxy. The armature coil is located inside the projectile and is constructed from 14 gauge square aluminum wire. Fig 4 shows the HCEML assembly mounted in the experimental test stand. Power for the HCEML experiment is supplied from a capacitive-based 8-module sequentially-fired pulsed forming network (SFPFN) [5]. Maximum SFPFN stored energy is 125 kJ. Table 1 lists the specifications for the solid-projectile HCEML.

Table 1. Solid-projectile HCEML specifications.

Parameter	Value
Barrel	
Inside diameter	40.0 mm
Outside diameter	76.0 mm
Length	305 mm
Projectile	
Length	85.0 mm
Outside diameter	39.5 mm
Mass	145 g

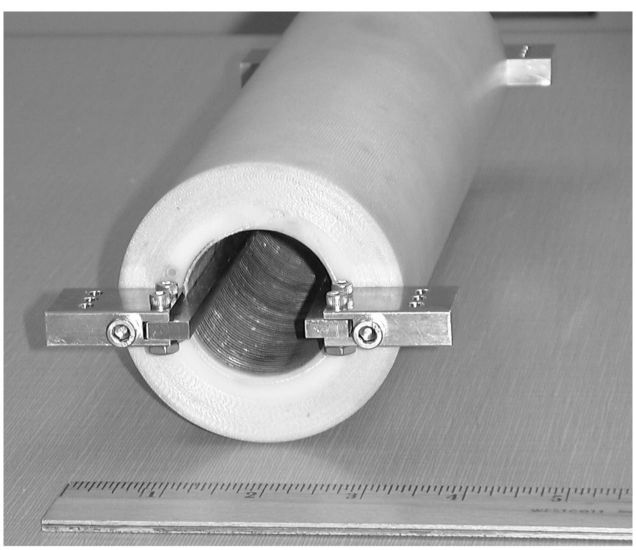

Figure 2. Construction of the solid-projectile HCEML barrel. Scale is in inches.

Figure 3. Construction of the solid-projectile HCEML projectile. Scale is in inches.

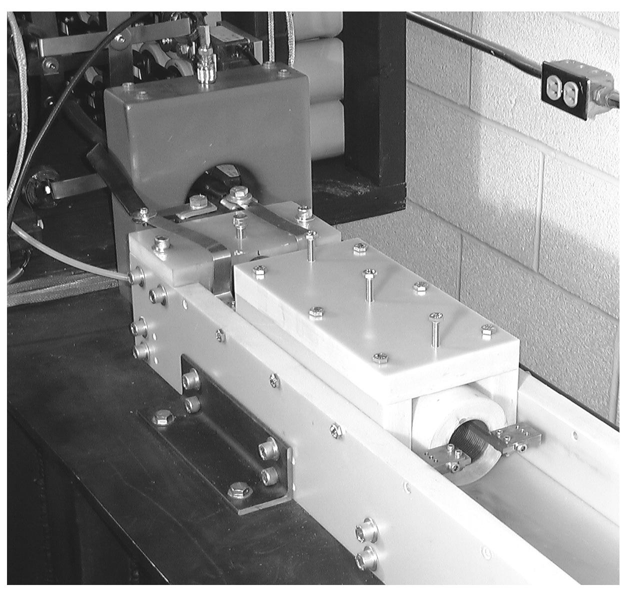

Figure 4. The solid-projectile HCEML mounted in the experimental test stand. Scale is in inches.

IV. EXPERIMENTAL RESULTS

A total of 6 tests were conducted using 3 solid projectiles. Table 2 lists the experimental test results from Test #3. The projectile mass is from Table 1.

Table 2. Experimental results for Test #3.

Parameter	Value
Charging voltage (all modules)	300 V
Peak current	7 kA
Projectile velocity	35.1 m/s
Efficiency	1.2 %

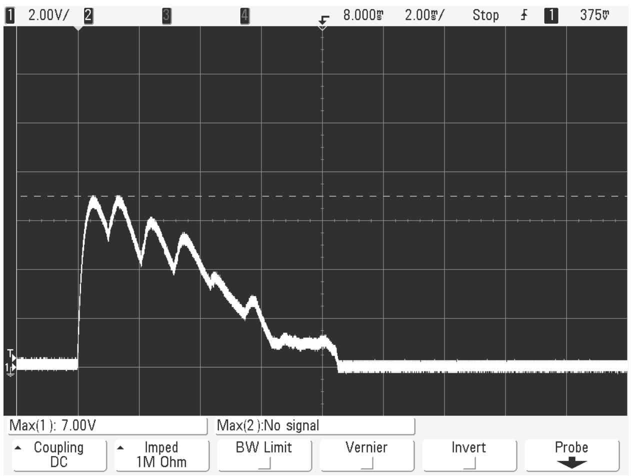

Figure 5. HCEML current from Test #3. Horizontal scale is 2 ms per division. Vertical scale is 2 kA per division.

Several mechanical and electrical issues with the projectile were noted from the 6 tests conducted in this experiment. The projectile housing had noticeable cracking from mechanical stresses generated during launch. Some internal electrical connections had also failed during launch due to high current. The barrel had displayed no noticeable signs of fatigue or wear and required only a minor cleaning between tests. The barrel remains in service today.

V. SUMMARY

A solid-projectile HCEML has been built and tested. To the author's knowledge, it is the first solid-projectile HCEML reported in the literature. The tests demonstrated the successful operation of the HCEML. While the first tests displayed the typical failures associated with an experiment of this kind, the authors are encouraged by the results and will continue development of the HCEML. Future tests will focus on the improving the HCEML design and performance. The goal is to improve the performance of the solid-projectile HCEML to those of existing hollow-projectile HCEMLs.

VI. REFERENCES

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